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Fuzzy and Sliding Mode Control Design for Vehicle Ride Performance

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(Abstract) The main objective of this paper is to use sliding mode and fuzzy controllers on a quarter suspension system of the vehicle to control it at different work conditions. In this paper, the simulation results show very good vehicle behavior under controlled actions in situations where the uncontrolled vehicle has undesired behavior. Sliding mode as a robust controller is employed to show the eligibility of this theory related to fuzzy logic method.

Keywords: Suspension System; Robust Control; Sliding Mode; Fuzzy Logic Controller.

1. INTRODUCTION

The Suspension system is an important part of automobile in the field of permanency and comfort ability. Frequently, it is designed in base of proper specification and type of usability. It is clear that, the output goes out of optimized point by going far from designing point and applying the various inputs. The semi active suspension by changing the property of material make create designing float points by applying a suitable controller and so create an optimized conditions for the suspension system. There are various methods to change the property of a material like changing the damping coefficient. In this paper, the object is to consider a controller based on sliding mode and fuzzy logic so that the overall operation of system can be optimized.

2. QUARTER SUSPENSION MODEL

There are so many models which have the ability to simulate the suspension system's behavior. But for designing the single station controller and simulator, a quarter model with two degrees of freedom is used. Because in this mode the complexity can't be a cause to change the output. An equivalent model for single station with the mass - spring system is shown according the figure (1), [1-3].

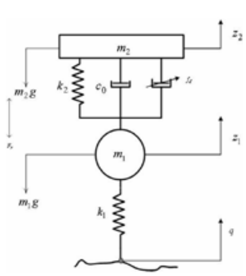


Figure 1. Mass- spring system for equivalent single station

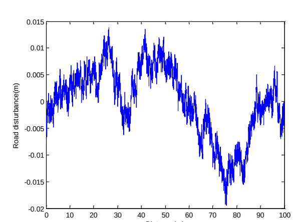
In this model, the number two masses is replaced with an equivalent sprung mass. This mass, contains the body Mass., mass of passengers and etc. The number one mass is also equivalent of wheel mass and is a portion of the suspension system mechanism. Equations of a quarter car model considering fixed values for spring stiffness are according to the relationship (1).

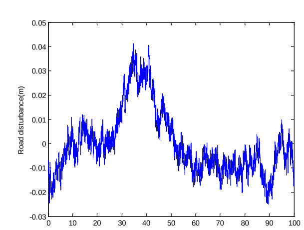
$$
\begin{aligned}
m_1 \ddot{z}_1 &= -c_0(\dot{z}_1 - \dot{z}_2) - k_2(z_1 - z_2) - k_1(z_1 - q) + f_d - F_r - m_1 g \\
m_2 \ddot{z}_2 &= -c_0(\dot{z}_2 - \dot{z}_1) - k_2(z_2 - z_1) - f_d + F_r - m_2 g
\end{aligned} \tag{1}
$$

Where m_1 is unsprung mass, m_2 is equivalent sprung mass, F_r is friction force, k_1 is equivalent spring stiffness of tire, k_2 is equivalent spring stiffness of suspensions system, c_0 is constant damping coefficient of MR damper and f_d is the nonlinear applying force of MR damper [4].

3. ROAD MODEL

The vehicle must be under the effects of input road profile for simulating the performance of the controller. For this purpose, a poor quality based on random vibration is produced; its longitudinal profile for 50 meters field is shown in figures 2 and 3. It is assumed in the road simulating that vehicle with constant speed 30 (km/hr.) traverses the whole of the path. Therefore the total tile of simulating is equivalent to 6 s [5].





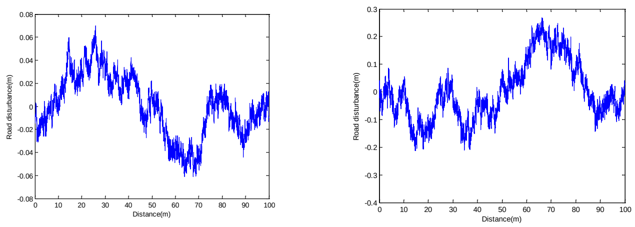


Figure 2. Road disturbance (m)

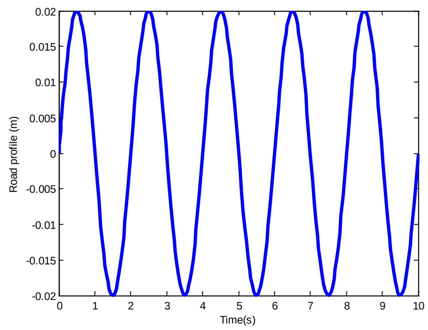


Figure3. Road Profile (m)

4. SIMULATION MODEL

There is an extended review of controllers used in suspension systems in literature. Among them, various types of approach like robust, adaptive, etc. are considered. In this paper, a powerful nonlinear controller based on sliding model and fuzzy sets Theory for modifying the nonlinearity in the suspension system is used. For designing the sliding mode and fuzzy Controller, first the equations of the model are written in the form of state space [6-9].

$$\begin{aligned} \dot{X} &= AX + BQ + EU \\ Y &= CX + DQ + FU \end{aligned} \tag{2}$$

Where the input and output matrices and road noise are defined below.

$$Y = \begin{Bmatrix} \ddot{z}_2 \\ z_1 - q \end{Bmatrix} \tag{3}$$

$$X = \begin{Bmatrix} z_1 - q \\ z_2 - z_1 \\ \dot{z}_1 \\ \dot{z}_2 \end{Bmatrix}$$

$$Q = \{q\}$$

The coefficient matrices for relation 6 extracted from relation 4 is carried out below.

$$A = \begin{bmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & -1 & 1 \\ \dfrac{-k_1}{m_1} & \dfrac{k_2}{m_1} & \dfrac{-c_0}{m_1} & \dfrac{c_0}{m_1} \\ 0 & \dfrac{-k_2}{m_2} & \dfrac{c_0}{m_2} & \dfrac{-c_0}{m_2} \end{bmatrix}$$

$$C = \begin{bmatrix} 0 & \dfrac{-k2}{m_2} & \dfrac{c_0}{m_2} & \dfrac{-c_0}{m_2} \\ 1 & 0 & 0 & 0 \end{bmatrix} \tag{4}$$

$$B = \begin{bmatrix} -1 \\ 0 \\ 0 \\ 0 \end{bmatrix} \quad D = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix} \quad E = \begin{bmatrix} 0 \\ 0 \\ \dfrac{1}{m_1} \\ \dfrac{-1}{m_2} \end{bmatrix} \quad F = \begin{bmatrix} \dfrac{-1}{m_2} \\ 0 \end{bmatrix}$$

5. SLIDING MODE CONTROL

One of famous and easy to implementation method of robust control is sliding control strategy. Spontaneously, it is based on the statement that it is much easier to control 1st order systems [10-12] . Let $e = x - x_d$ be the tracking error of the variable x, where x_d is the desired value for x which is given to the controller. Furthermore, let us define a time-varying surface $e = x - x_d$, for a first-order problem, by the scalar equation:

$$S = ce + \dot{e} \tag{5}$$

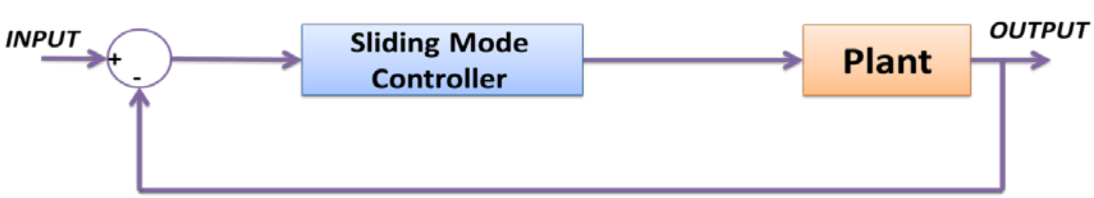


Figure4. Sliding mode and plant block diagram

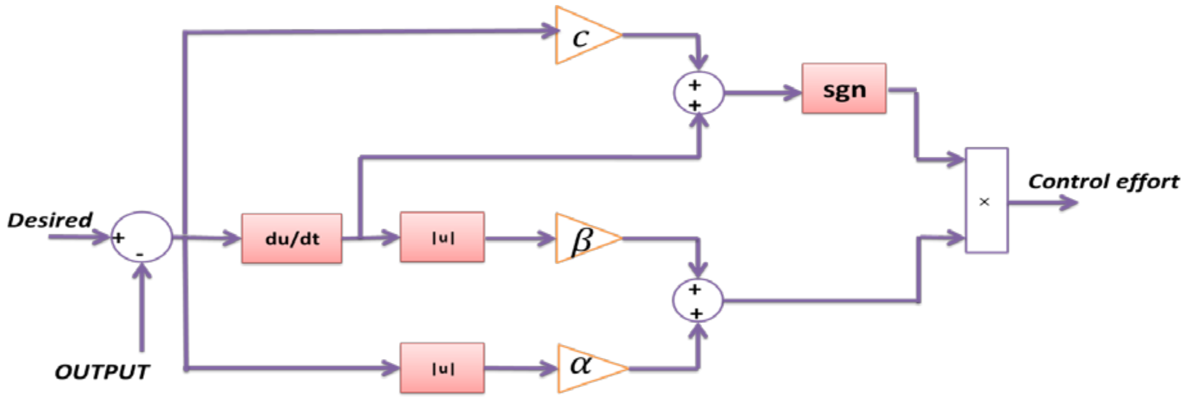


Figure5. Sliding mode detail

Sliding mode control is a type of robust control where the dynamics of a nonlinear system are changed through submission of a high-frequency switching control. In this paper, sliding mode control is used to oblige the vehicle sprung mass acceleration to lie within a region of the desired value. This design method contains of two modules. The first, includes the design of a switching function so as to the sliding motion fulfills strategy conditions. The following is well-looked-after with the selection of a control law, which will make the switching function attractive to the system state.

In this paper, the proportional switch law is used to design the controller u [13].

$$u = \left(\alpha|e| + \beta|\dot{e}|\right)\mathrm{sgn}(S) \tag{6}$$

This controller strategy is modeled and schematic plot is shown in figure 4 and 5.

6. FUZZY CONTROLLER DESIGN

A very close to the human behavior controller is named fuzzy. This concept has been introduced by Professor Lotfizadeh and extended by so many researchers. An inclusive review of the fuzzy logic can be found in literature. Fuzzy logic controller has developed in software packages like MATLAB as a toolbox [9, 14-19]. Fuzzy logic control is a nonlinear regulator technique and operative in treatment the uncertainties and nonlinearities related to the complex control structures.

This controller can be organized as follows: Fuzzification, Rule set and defuzzification. The input–output memberships are shown in Figs. 6 and 9. The input membership functions are Gaussian2 curves, while the output membership functions are Gaussian curves [20].

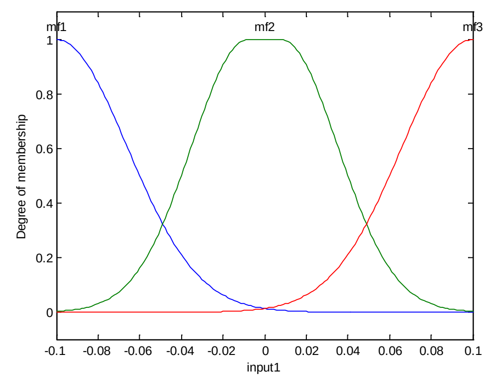


Figure6. Membership function for input in fuzzy controller design

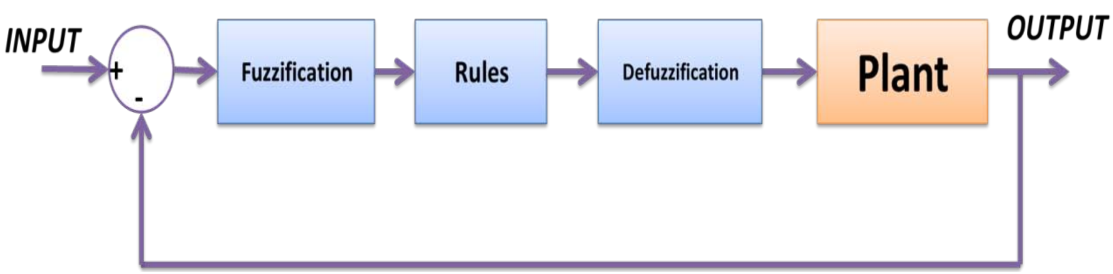


Figure7. Fuzzy and plant block diagram

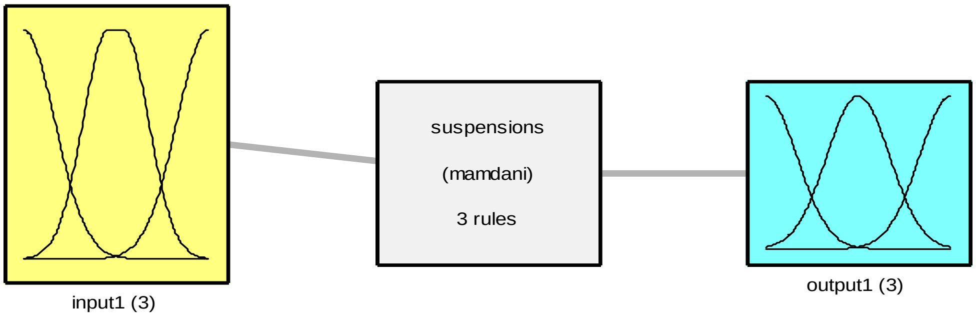


Figure8. Fuzzy structure

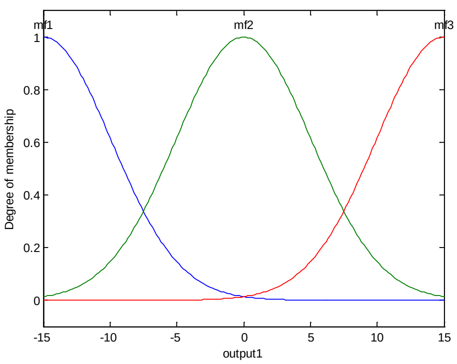


Figure9. Membership function for output in fuzzy controller design

7. SIMULATION AND RESULTS

Parameters imported in table (1) are used as vehicle model parameters. Damper model and controller on discussing road are modeled and simulated in MATLAB-SIMULINK.

Table 1. Vehicle parameters

Parameters	Value/ unit	symbol
Sprung mass	396 Kg	m_2
Unsprung mass	48 Kg	m_1
Tire stiffness	220000 N/m	K_1
Equivalent spring stiffness	35000 N/m	K_2
Equivalent damping coefficient	600 Ns/m	C

The variation of distance between sprung mass and unsprung mass for three conditions is shown in figure 10. This variation is so clear for SMC whereas the fuzzy controller doesn't have this effect on.

The magnitude of normal acceleration applied on passenger is shown in figure 11.

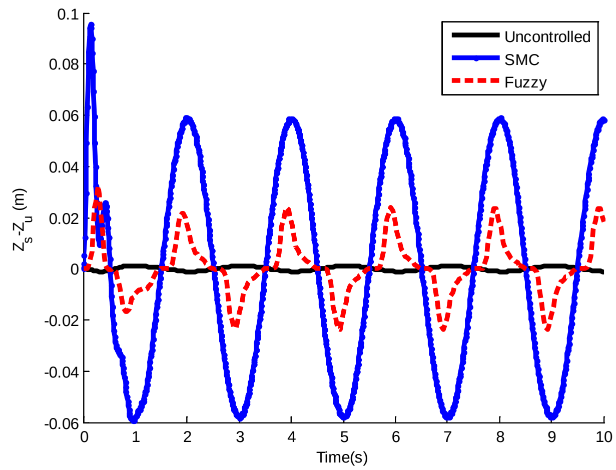


Figure10. The variation of distance between sprung mass and unsprung mass for three conditions

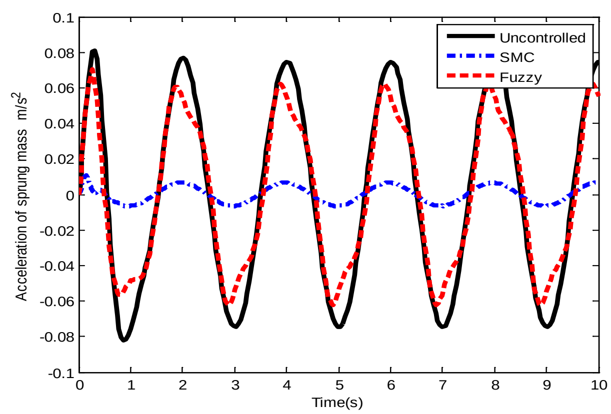


Figure 11. Acceleration of sprung mass

They are in three states: without a controller, Fuzzy and Sliding mode controller. As this figure shows, Performance of sliding mode controller is eye caching while fuzzy theory can't decrease the acceleration glowing. SMC is reviewed in the previous section and discussed about its robustness. This robust controller is more accurate and efficient. In suspension system, because of some uncertainties in vehicle dynamics and road conditions, only a robust controller can do well. Using a truthful controller like SMC needs a major cost in designing

actuators and down layer controllers must be designed with its benchmarks. In figure 12, the control effort shows a difference between the energy that each of these controllers is using.

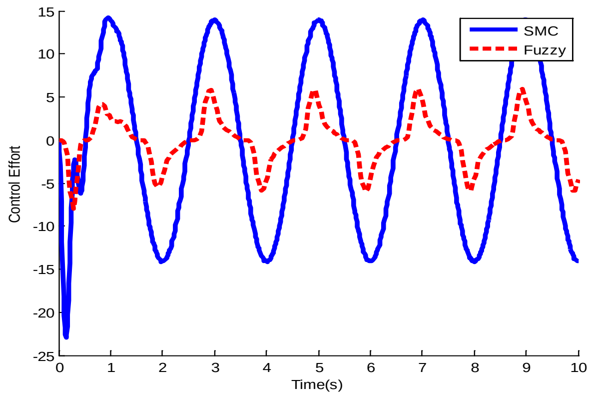


Figure 12. Control Effort

As this figure indicates, Controller effort in SMC rises up. At the first time of motion, an instantaneous effort is used. This is due to inconvenience road. This downs hoot is settled after one second and the system is returned to a stable point.

8. CONCLUSION

In this paper, various types of controller contain a nonlinear controller base on sliding mode and fuzzy Controller. The aim is to decrease the acceleration applied to the center of vehicle mass. The dampers are adjustable and tuned fluid which has the nonlinearity behavior. The simulation results showed the designed controller could decrease the vibration loads applied normally on the coarse road. Results showed that using sliding mode can modify systems dramatically but control effort in this mode is raised up fast. Whereas fuzzy controller is not as fine as sliding mode but its effort is meaningful

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